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PAVEMENT CRACKING INVENTORY STUDY

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16. Abstract

The purpose of this project is directed at reviewing available techniques and equipment in selecting and developing a video-logging system used in obtaining a crack index for use in Arizona Department of Transportation Pavement Management System. During the first phase, a literature search was accomplished to evaluate all the electromagnetic means to gather the surface defect inventory including cracking. It was concluded that the video technology provided the best means of gathering this information and field tests were conducted with individual types of video cameras. High resolution color cameras provided the best means of computer enhancement of the video images were explored.

In Phase II, field tests were conducted on four one-mile test sections of asphalt pavement in various states of distress. The field video images and the standard ADOT crack reference pictures were computer enhanced and a methodology was developed to directly compute the area of cracking.

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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Arizona Department of Transportation (ADOT) has been a leader among the several states that have developed pavement management programs. Pavement management programs determine and justify the proper funding levels to provide a safe and well maintained highway network for the traveling public. Within the Arizona pavement management system, ADOT has been able to use pavement test equipment to measure the pavement's surface roughness and skid resistance. However, the third factor, pavement cracking, is not measured by some standard mechanical-electrical test device.

Pavement cracking and the rate of change in cracking appears to be a very reliable and consistent indicator for pavement maintenance. Cracking indicates distress due to either traffic or climatic factors or a combination of both. Once cracking appears, the factors which influence its appearance will continue to operate and accelerate. The more extensive or severe the cracking, the sooner some form of rehabilitation must be initated.

The heart of the pavement management system is the predictive relationship that determines the future pavement condition of each highway pavement section. Cracking, caused by thermal or traffic fatigue and aging, is an important factor that must be included in the predictive relationships. The ADOT has developed a crack index system to determine the percent cracking by area. The system is based upon comparing standard test photographs (on which the percent of cracking has been calculated) to the cracking actually found in the field on the first 1000 sq. feet (90 m^2) of pavement surface at each milepost. Annually, the program is updated with the crack index and percent change in cracking from the previous year for each mile of pavement.

The system is slow with an annual expenditure of $30,000 to gather the pavement crack index information. New technology has been developed over the past several years that offers great promise for developing quicker more reliable systems from which the cracking index can be developed for the ADOT pavement management system (ADOT PMS).

SCOPE

The scope of this project was to review available techniques and equipment, select and develop a video logging system from presently available video equipment, and obtain the crack index for use in the ADOT PMS. The project was divided into two phases to accomplish the overall program scope.

Phase I

During Phase I, a review was made of the techniques and equipment available to determine the most cost effective system for visually recording and evaluating pavement cracking. A feasibility study was made to determine if computerized video image enhancement could be used to measure the amount of cracking in pavement test areas.

Phase II

The second phase of the project was a field test to demonstrate that the selected video system is operational and how to produce the cracking index for the ADOT PMS. An adjunct to this phase would be the field testing of various types of video equipment to determine the best operational procedures, camera angles, lighting, camera height, and various video techniques to be used within the system.

Task List

The following tasks were accomplished to complete both phases of the project:

(1) A review was accomplished of various types of video equipment along with preliminary field testing for suitability in the pavement cracking study.

(2) A literature review was accomplished on pavement surface distress measurement and recording systems with special emphasis on cracking.

(3) Electronic equipment that provides enhanced images through new computer programs was studied for possible utilization in determining the ADOT crack index.

(4) A detailed field test was conducted using various quality levels of video equipment to determine the feasibility of the use of video technology and the quality level required to obtain the ADOT crack index.

(5) The final task was to demonstrate computer enhanced video image capability in conjunction with calculating the percent cracking of the pavement test sections.

DISCUSSION

Video Equipment

After a survey of the available video equipment, four companies were invited to demonstrate their equipment. These were JVC, Panasonic, Hitachi, and Ikegami. Each of these companies demonstrated its newest color and black and white television cameras and recorders. From the field demonstrations that were performed in the Chicago area, it was determined that the current models of video equipment will provide sufficient resolution and clarity to view the surface cracking, distortion and texture. The surface texture was particularly clear on color television cameras that had resolution greater than 500 lines. The highest resolution cameras are black and white with up to 1,000 lines. However, with a black and white camera the surface texture is not as clear as it is with a high resolution color camera.

The literature review, discussions with knowledgeable engineers and field tests confirmed the original hypothesis, that the video methodology was the most productive means of gathering the pavement cracking information

Pavement Surface Distress Measurement & Recording Systems

Both manual and automated literature searches for the current practices for measuring and recording pavement surface distress were used. Manual literature searches were made in the libraries of Northwestern University Transportation Center, Evanston, Illinois and Novak, Dempsey & Associates, Palatine, Illinois. These were used to refine the list of key subject areas subsequently used for the automated search in the National Technical Information Service & Highway Research Information System. The key words of Pavement Management, Highway Pavement Evaluation, Surface Defects, Roughness and Cracking were most productive. The literature search showed that the majority of the information was found under pavement management systems or in the various handbooks developed by the local state agencies to accomplish their own surface evaluation surveys.

Since the mid 70's no additional pavement distress mechanisms have been added to the state of the art of pavement surface condition rating systems nor have any new methods for determining crack counts been developed other than photographic methods (1).

Each state has implemented its own surface condition rating system to satisfy its own requirements for its pavement management system (1).

All of the surface study methods have a commonality of recording the following major surface distress categories.

a. Cracking (longitudinal, transverse, alligator, map, reflection, corner, edge).

b. Disintegrations (ravelling, stripping, spalling, scaling).

c. Permanent Deformation (Rutting, Faulting)
d. Distortion (Settlement, Heaving)
e. Surface Conditions (Flushing, Polishing)
f. Repairs - (percent patching, or destruction)

The majority of the surface condition rating systems rate only the severity of each distress category. The severity refers to the size or degree of the distress manifestation, i.e., a 1/16 inch or a 1/4 inch crack. The severity is normally rated either with a word scale (low, medium or high) or a numerical value ranging from zero to five or zero to ten. The density is rated as how often the distress occurs over the area of the test section. Two schools of use of this information on the severity and density have evolved. The first is a one number rating system which combines both severity and density and then deducts this value from 100 to arrive at a pavement condition index. This is similar to the Asphalt Institute method (2) and the method used by the United States Air Force for air field pavement condition index (3). The second technique is a two number rating system in which the severity and density are added and the sum is deducted from 100 to give a surface condition number. This is the method used by the Ontario Ministry of Transportation and Communication (4). A further refinement of this method is to also deduct a factor for the location of the distress on the test section, e.g. if it is in the wheel path.

While some agencies have used photologging to accomplish limited surface evaluations, the visual method has remained the predominant means of gathering the surface condition information. Visual surveys continue to be plagued by undesirable subjectivity on the part of the raters, the absence of valid workable statistical sampling procedures and the lack of uniformity and severity weighting techniques for the distress types (1). While there is general agreement on what to look for during the surface evaluation, particularly for cracking, new survey methods would be helpful to quickly gather the field data and produce a uniform surface evaluation system free of rater bias.

Surface Evaluation Utilizing Video Technology

The use of television by highway agencies has been limited to video logging the street scene and traffic sign inventories. Some municipalities have also kept a video record of the existing street scene for use in any potential lawsuits. However, very little has been done with video in conducting surface condition evaluations.

Video Equipment

In general a video system will consist of the video camera; lens; lens or camera body stabilizing equipment; video image recorder and monitor; lighting and distance measuring information equipment. Recent technological improvements have made video equipment, particularly the new cameras, highly portable and compact.

a. Color Video Camera Color video cameras are manufactured with either a single tube or a three tube color system. Within the single tube camera the three color elements, red, green and blue are combined together in a single tube arrangement. This type of camera has resolution of between 250 and 300 lines with a price range that is comparable with that of a black and white camera ($2,000 to $5,000). In a three tube color TV camera each color element has its own corresponding color tube arranged along the X,Y, and Z axis. This camera gives about 500 lines of resolution and has a very clear picture. Three tube color cameras are available in both medium price ranges ($12,000 to $15,000) and expensive price ranges exceeding $35,000+. The quality between three tube cameras is measured in the amount of gain (the ability to amplify light) and the signal to noise ratio. These properties have a significant effect on the overall quality of the picture. The field tests of the JVC and Hatachi Three Tube, Color Video Cameras showed remarkably clear images of the pavement surface cracking, distortions and texture.

b. Television Recording Tapes The 1/2 - 3/4 inch (12.7 to 19 mm) tapes have a resolution capability up to 400 lines. The one inch (25.4 mm) tape can record up to 500 lines of resolution. The tape size selected will be governed by the recorder that is selected for the system.

c. Video Recorders The new video tape recorders (VTR) come with a multitude of features that include the normal forward and reverse, as well as frame by frame monitoring and variable speed recording. High quality 3/4 inch (19 mm) VTR as well as studio quality recorders were selected for the field test. The standard recording rate for VTR's is 30 frames a second. The recording rate will permit the taping of the pavement surface from a moving vehicle.

d. Video Monitors Although there is a small TV screen on each of the TV cameras, a monitor (i.e., a TV set) is required in the test vehicle to insure that the proper information is captured. A 9 inch (228 mm) color monitor was selected and mounted on the dash for viewing by the driver.

e. Video Camera Support The initial field experiments showed that it was necessary to stabilize the camera to reduce the large scale vibrations inherent in a moving vehicle. Accessories have been developed to overcome this problem. Either a spring stabilized camera stand, which can be either hand held or mounted on the vehicle, or an image stabilizer may be used. The image stabilizer uses a gyroscope and mirror configuration which stabilizes the lens image taken by the camera and produces a quality picture free from vibrations. The image stabilizer has an inherent problem with wide angle lenses (35 mm or lower), in that it vignettes and loses quality around the edge of the image.

f. Camera Angle The recommended camera angles and lens elevations were determined during the initial field evaluations of the video equipment.

The camera angles were run from a direct vertical downward (90°) to slightly depressed position (10°) from the horizontal. The lens elevation was run from 39 inches (100 cm) to 120 inches (304 cm) above the pavement surface. From these preliminary tests, it was determined that the camera angle should be 45 degrees from the horizontal at an elevation of 120 inches (304 cm).

g. Lens The best configuration for focal length and angle inclination was an eight milimeter wide angle lens mounted at 45 degrees from the horizontal, which provides the desired 14 foot (426 cm) wide by 14 foot (426 cm) deep picture image. This also can be obtained by using zoom lenses on the TV camera.

h. Mounting Supports and Lighting The video cameras were supported to provide an elevated viewing position of at least teñ feet (304 cm) above the road surface. Lighting should be used to provide continuous contrast to highlight surface cracking.

Video Image Enhancement Using Computer Technology

Computer enhancement holds great promise in automating the calculation of the ADOT cracking index. Computer enhancement has already been used in studying very small cracks associated with fatigue cracking in steel bridges (5).

The first step in computer enhancement is to digitize the video image. In digitizing, the image is broken up into dots called pixels, much like a photograph is printed on newsprint. The pixel is the basic element of picture resolution in computer enhancement. It is operated on an X and Y coordinate system where X is 640 horizontal columns and Y is 480 vertical rows. The Z axis is the gray scale value which ranges from 0 to 256. Zero is black and 256 is white (6).

There are approximately 13 different functions available for computer enhancement (7). The two main activities that image processing accomplishes are to either enhance reconstruction of the original image which produces a new image or to develop a numeric report which produces numbers representing the image.

The enhancement processes take this basic data and, by working it mathematically, enhances the image by magnification, averaging the gray level or modifying the gray levels. The image enhancement processes that hold the greatest promise for the crack index study are contrast enhancement and edge enhancement (difference, gradient and laplacian).

a. Contrast Enhancement The human eye is more sensitive to the high contrast picture. Therefore, by expanding the middle level gray scale into a wider band of gray while making the low level blacker zone black and the high level all white, small details become more defined. The contrast enhancement algorithm can also be reversed to enhance the darker areas instead of the lighter areas. This last method may be very good for crack studies.

b. Edge Enhancement (Difference) - The original picture is shifted by one pixel in both the horizontal and vertical direction. The two pictures are then compared and one is subtracted from the other. If there is a difference in the gray level, as around the edge of certain features in the picture, then these will be enhanced through subtraction.

c. Edge Enhancement (Gradient) - In gradient methods the same subtraction as for the edge enhancement (difference) is calculated. Since these differences are the first derivatives of the gray level, a gradient is calculated as the square root of the sum of the squares of the vertical and horizontal derivatives. This produces an edge enhanced picture where the edges are calculated without regard to shifting direction of the image, i.e., a picture with white lines on a dark background.

d. Edge Enhancement (Laplacian) - This is based on the second order derivative. Maximum values or peaks within the image are emphasized. This is very much how the human eye sees an object. This gives a much more natural and detailed image. When combined with the original picture, a very clearly detailed picture of the original image is obtained.

A comparison software program could be developed to determine the ADOT crack index (5). The digitized video images could either be compared against any number of standard cracking index pictures, or the precise area of cracking in the image can be determined. This can be accomplished any number of times along the one mile test section to more precisely measure the percent cracking and the annual change in cracking.

Field Tests of Video Equipment to Accomplish Surface Evaluation

Test Areas

The broad classifications of Arizona Highway Regions are desert, transition and mountain. The original test program for an urban and rural test section within each region was modified by ADOT to rural highways in the transition zone. Asphalt and portland concrete test areas were also modified to asphalt pavements, since the preponderance of ADOT highways are asphalt.

Surface Evaluation Procedures

The video surface evaluation information was correlated through regression analysis with existing surface evaluation methods. The following methods were used:

a. ADOT photo comparison method to provide comparison with existing methods to determine the ADOT crack index.

b. The Asphalt Institute Pavement Evaluation Rating System - A numerical survey combining severity and density of different distress manifestations.

c. Ontario Ministry of Transportation and Communications (Novak, Dempsey & Associates) condition rating system for flexible pavements. A comprehensive two number rating system reflecting both severity and density of different surface distress manifestations particularly cracking.

<u>Video Equipment for the Field Test</u>

Video equipment representing three levels of sophistication (high, med, low) was used in the field test. This performance range would permit the selection of the most economical ADOT video logging system. The video equipment selected for the field test by level of sophistication was as follows:

a. <u>Video Cameras</u>

1. High: Hitachi SK 91-Color, three tube, high resolution, 500 lines, dichroic prism optics, Cost $40,000.

2. Medium: JVC KY 2700-Color, three tube, high resolution, 500 lines, dichroic mirror optics, Cost $14,000
JVC KY1900-color, three tube, medium resolution, 300 lines, dichroic mirror optics, Cost $7,200.

3. Low: Panasonic WV 1850, black and white, high resolution, 800 lines, cost $1574.

b. <u>Video Tape Recorders</u>

1. High: Hitachi HR-100, 1 inch (25.4 mm) tape, high resolution, $33,000.

2. Medium: JVC CR 8200 U, 3/4 inch (19 mm) tape - medium resolution, stop frame. Monitor, $5,600.

c. <u>Video Monitors</u>

1. Vehicle: JVC 9 inch (228 mm) color. Model S100, $400.

2. Office

   a. High - Ikegami - 17 inch (432 mm) color, high resolution precision quality monitor, Model No. PM171P, $600.

b. Medium - Sony Trinitron 19 inch (432 mm) medium resolution, Model No. KV1713G, $550.

c. Low - Ikegami 17 inch (432 mm) B/W -high resolution, Model No. 125A, $345.

d. Video Image Stabilizing Equipment Steadicam - Hand held or mounted spring-stabilized camera mount, $25,750. For the normal operation in video logging, the spring-stabilized camera mount would be required at cost of $6,000.

e. Distance Measuring Equipment to Provide Date and Mile Post Information on the Video Tape

1. Measuring equipment: Numetrics Model No. K 145 with Binary coded Decimal Generator, $725.

2. Video Character Generator - Chrono-Log Corp., Model No., S92, 131-X-11, $1,658.

NOTE: For the field test, the mile-post (MP) information and the test speed were recorded on the video tape.

f. Vehicle and Equipment Set Up

A 25 foot (762 cm) recreational vehicle with a built-in 125 volt power source was used for the test program. A platform was mounted on the top of the front of the vehicle to support the camera operator and the various video cameras. The height of the camera lens was 10 feet (304 cm). The Steadicam system and the rigid camera mount were mounted on the front of the platform. The general view of the camera arrangement is shown in Figures 1 and 2. The Steadicam system, which is designed to steady the camera in any position, was hand supported by the operator. A video console system and VTR's were installed in the vehicle. An intercom system was used by the video technician to monitor and direct the video taping. The driver had a nine inch color monitor mounted on the dashboard to view the recorded scene and comment on the pavement conditions as the tests progressed.

Speed

Speed of the test was measured by the vehicle speedometer. The speed for each test was superimposed on the video image by use of the special effects generator for the first 200 feet (61 m) of the test run.

Recording

During each test run, the recordings were taken on the Hatachi HP 100, 1 inch (25.4 mm) tape, and the JVC CR 8200U, 3/4 (19 mm) tape, VTR's.

FIGURE 1.
SIDE VIEW,
VIDEO CAMERA
SET UP.

FIGURE 2.
FRONT VIEW,
VIDEO CAMERA
SET UP.

Field Test Sites

The asphalt pavement test sites were selected by ADOT. There were four 1-mile test sections (located on Figure 3) described as follows:

(a) The first test site was on State Route 87, a north-south rural inter-city highway south of Chandler, Arizona between Mileposts 160 and 161. This is a 4-lane asphalt highway. The pavement surface cracking condition is characterized by fine to medium alligator cracking with some longitudinal cracking in the wheel tracks as shown in Figure 4. The video test was taken on the morning of the 15th of December shooting with the sun behind the vehicle which was proceeding in the north bound direction.

(b) The second test site was on State Route 287, from Mileposts 135 to 136. This is an east-west route located west of the city of Florence, Arizona. The pavement is characterized by transverse cracking, block cracking and random cracking as shown in Figure 5. The video test was taken in the afternoon of the 15th of December in the east bound direction with the sun at the right rear of the vehicle.

(c) The third test site was on U.S. Route 89, from Milepost 130 to 129. This is a north-south route south of Florence, Arizona. The pavement is characterized by transverse and random cracking and some patching as shown in Figure 6. This test site was selected for the detailed surface evaluation study because of the clarity of the video images obtained at this test site. The video test was conducted on the morning of the 16th of December on the south bound lane shooting into the sun.

(d) The fourth test section was on State Route 87/287 from Milepost 125 to 126. This is a north-south route located south of Coolidge, Arizona. The pavement is characterized by transverse cracking with sealed joints as shown on in Figure 7. The video test was taken on the south bound lane with the sun position ahead and to the right. This test section also had one area of cracked portland cement concrete pavement. This cracking was seen on the video tapes quite clearly.

Video Test Procedures

Test Lane Layout

Each test was conducted in the same manner. First, each mile (1.6 km) of pavement was laid out in 200 foot (61 m) increments in the test lane using a measuring wheel. Each section was then numbered from 1 to 26 to accurately locate each of the video images for that test run.

Test Speeds

The test runs were made at speeds of 5, 10, 25 and 35 miles per hour (8,16,40 and 56 km/hr). The variable speeds were used to determine the

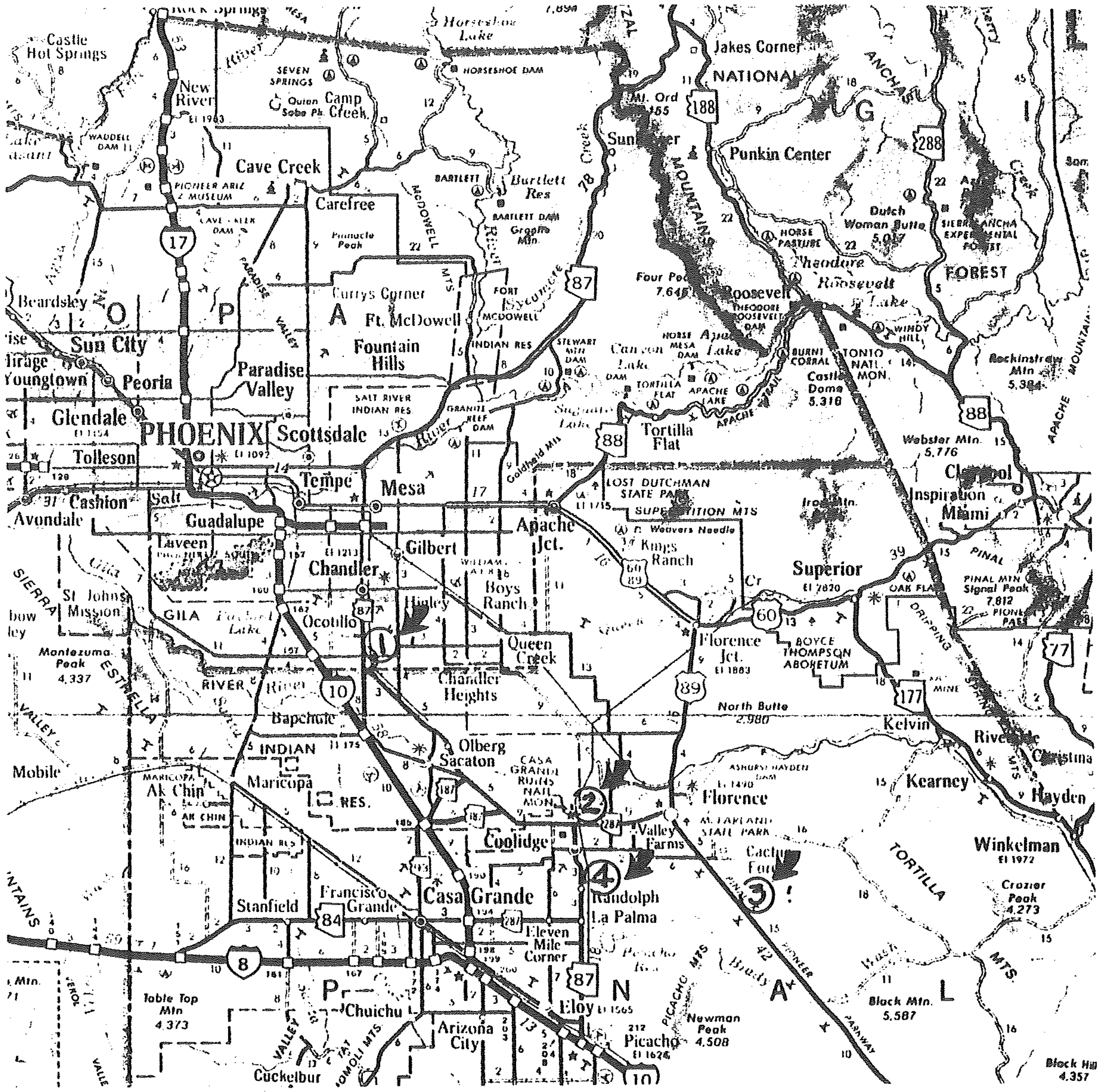

FIGURE 3
TEST SITE LOCATIONS

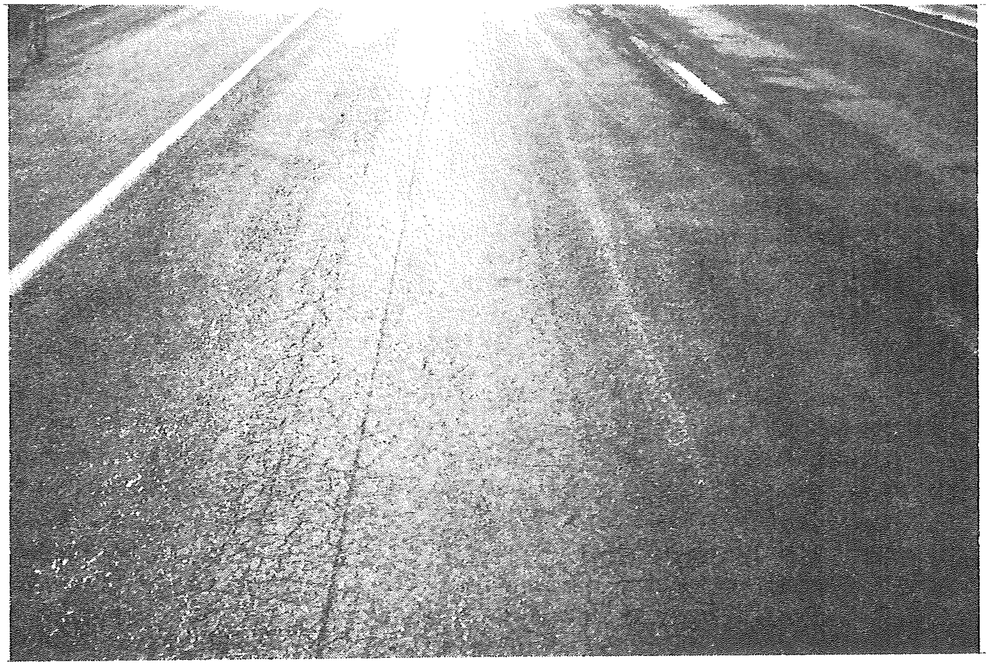

FIGURE 4.
TEST SITE 1, SR 87-OUTSIDE N BOUND LANE.

FIGURE 5.
TEST SITE 2, SR 287-E BOUND LANE.

FIGURE 6.
TEST SITE 3, US 89 SE BOUND LANE.

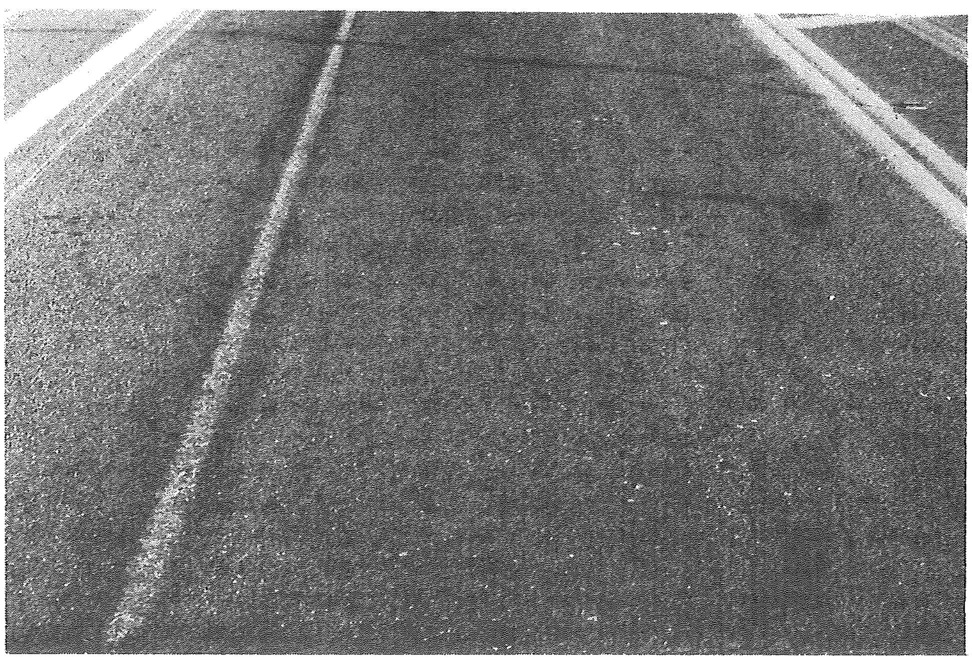

FIGURE 7.
TEST SITE 4, SR 87/287 S BOUND LANE.